



CRYOGENIC VAPORISATION SYSTEMS – PREVENTION OF BRITTLE FRACTURE OF EQUIPMENT AND PIPING

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1. Introduction

Cryogenic (or cold) fluids may be inadvertently admitted to process piping and equipment due to the malfunctioning of cryogenic liquid vaporisation systems, which can result in catastrophic failure due to brittle fracture. When certain metals, typically carbon steels, become cold they undergo changes in their structure, which makes them less ductile i.e., they become brittle. Other metals such as stainless steels, aluminium, brass, copper, etc., do not exhibit this ductile/brittle transition and remain ductile at low temperatures. This ductile-to-brittle transition can cause an existing defect in a material to propagate to a crack, or even start a crack with no additional increase in stress. A brittle failure of an item is more destructive, as the crack propagates rapidly, and sections of material may become detached, whereas with a ductile failure the material 'tears' and the pressure is vented in a more controlled fashion.

2. Scope and purpose

This document applies to cryogenic liquid supply systems, located either on a customer site or a production site, where cryogenic liquid is vaporised and is then supplied either as the primary or secondary source of gaseous product.

The secondary source of supply is normally used as a back-up supply to a production plant when the production plant trips or is shut down, or to supplement customer demand where it exceeds the capacity of the production plant ("peak-shaving").

Cryogenic fluids covered are:

- Liquid Nitrogen
- Liquid Oxygen
- Liquid Argon
- Liquid Hydrogen
- Liquid Methane
- Liquid Ethylene

The supply systems work by vaporising cryogenic liquid, typically in response to decreasing pipeline pressure.

Systems are made up from the following:

- A liquid supply from either a low-pressure tank and pump arrangement, or directly from a high- pressure tank,
- A vaporisation system that could be an ambient air type or one that utilises an external energy source e.g. steam, hot water, electricity, direct fired, etc.

This document does not cover the following situations:

- Air separation and other cryogenic processes with columns, separators, or tanks in which a gas stream from a sump is normally supplied through downstream heat-exchange equipment.
- Piping systems within which a fluid is expanded across a valve or restriction with the resultant temperature being below the ductile to brittle transition temperature (DBTT) for the piping system.
- Vessels that are depressurised rapidly - as work is done in a vessel by a gas expanding as it is discharged out of the valve, the temperature inside the vessel and the vessel wall may be lowered.

This document has been written to identify the hazards associated with cryogenic liquid vaporisation systems and to recommend the safeguards to be taken. It recommends safe practice for the design of

new cryogenic vaporiser systems. For existing systems a risk assessment shall be undertaken to establish if any modifications are required.

3. Definitions

3.1 Brittle fracture

Brittle fracture is the term given to a failure caused by a crack which propagates rapidly through the material. A brittle material has little resistance to failure once the elastic limit has been reached. These failures release a lot of energy and are dangerous, as fragments of the material may be thrown long distances.

3.2 Ductile

The property of a metal that allows it to elongate, with a rapid increase in local stresses, prior to failing.

3.3 Fail Safe Systems

A system is considered to be "fail safe" if, under all reasonable expectations of in-service malfunctions or component or wiring failures, the aggregate response of the system is to create a situation where no dangerous situation is created and a "safe performance response" can be reasonably expected.

3.4 Flow Reduction Systems

These are systems employing vaporisers where it is accepted by the customer or the process that the flow can be reduced. The low temperature protection system (LTPS) shall be designed to throttle flow to correspond with the energy available to the vaporiser.

3.5 Flow Restriction Systems

A properly designed restrictive orifice or other fixed device installed immediately downstream of the vaporiser to limit the flow to a maximum value.

3.6 Toughness

The ability of a metal to distribute internally any stress caused by a suddenly applied load; it is the opposite of "brittleness", which implies susceptibility to a sudden failure.

3.7 Uninterruptible Supply Systems

These are systems employing vaporisers, where, due to safety reasons, the system is designed so that the flow to the process or end user cannot be interrupted. e.g.

- Inert gas blanketing for a hazardous atmosphere or process.
- Oxygen supply to a health care facility.

The following standards are relevant to these situations:

NFPA 50 - Standard for Bulk Oxygen Systems at Consumer Sites [1].

NFPA 86C - Standard for Industrial Furnaces Using a Special Processing Atmosphere [2].

EN 737-3 1998 - Medical gas pipeline systems - Part 3: Pipelines for compressed medical gases and vacuum [3] (to be replaced by EN ISO 7396-1 - Medical gas pipeline systems, in due course [4]).

NFPA 99 - Standard for Health Care Facilities [5].

3.8 Utility and utilities

The terms utility and utilities as they appear in this document address the means to supply heat to a vaporiser designed to vaporize cryogenic liquids and include all of the following applications:

- Electrical power to drive hot air or ambient air fans, blowers, water or fuel pumps, and immersion or radiant heaters or electrically heated metal block vaporisers.
- Supply of fossil fuels, including natural gas or fuel oil, which is combusted to generate heat or steam.
- Steam supplied from a customer or other source.
- Other sources of pumped or circulating heating fluids such as water baths, hot water streams, glycol-water streams, heat-transfer fluids, or similar forms of process or waste heat supply.

"Utilities" do not include natural draft/ambient air vaporisers. Utilities do include fan ambient/forced draft vaporisers.

3.9 Vaporiser

A heat exchanger which changes the state of a cryogenic liquid to a vapour, by transferring thermal energy from an external source to the fluid.

3.10 Pressure

In this document bar shall indicate gauge pressure unless otherwise noted –i.e., (bar, abs) for absolute pressure and (bar, dif) for differential pressure.

4. Causes and Consequences of Low Temperature

4.1 Causes of low temperature

Some of the causes of low temperature at the outlet of a vaporiser are listed in the following table:

Table 1 - Causes of low temperature

Type of vaporiser	Cause of low temperature	Example
All types	Customer overdraw exceeds design capacity, particularly for an extended period.	Customer adds extra equipment which requires additional flow capacity without notifying the gas company.
All types	Flow exceeds rated capacity of the vaporiser.	Relief valve on pipeline opens and sticks open Prolonged venting downstream of vaporiser.
All types	Pipeline pressure or flow control valve goes fully open.	Control valve actuator failure. Control valve positioner malfunction.
All types	Control system fails in a way such as to create a low temperature at the vaporiser.	Failure of basic pressure control or flow control system.
Ambient vaporiser or forced draft, fan ambient vaporisers	Vaporiser heavily iced due to high demand, peak-shaving, main gas supply plant trips out etc.	Vaporisers are rated for a given flow rate and time. If this is exceeded gas outlet temperature may drop.
Ambient vaporiser or forced draft, fan ambient vaporisers	Vaporiser heavily iced.	With a vaporiser changeover system, a changeover valve failing to move to the correct position will lead to this situation.
Ambient vaporiser or forced draft, fan ambient vaporisers	Low ambient temperature for prolonged period does not allow opportunity for defrosting the vaporiser.	Failure of timed changeover if fitted. Poor siting of vaporiser where it cannot defrost. Changes to layout around the vaporiser which affect its efficiency (walls built close by).
All water bath vaporisers	Low or no water level in water bath.	Drain valve left open. Leaks in water bath. Water / Steam supply system failure.
Steam vaporisers	Steam control valve fails to open. Steam supply from boiler fails.	Valve actuator failure. Positioner malfunction. Controller malfunction. Superheated steam boils off contents of water bath.
Electrically heated vaporisers	Failure of electrical heating. .	Electrical power supply failure. Switchgear fault. Heater element burns out.
Fired heater water bath vaporisers	Fuel gas failure.	Burner management systems malfunction. Loss of fuel supply.
Forced draft, fan ambient vaporisers	Fan stops. Defrost heaters, where fitted, do not operate.	Electrical power failure. Switchgear fault. Fan mechanical failure.
Ambient air vaporisers with trim heaters	Trim heater unable to maintain gas temperature above required minimum temperature.	Electrical power failure. Switchgear fault. Heater elements burn out. Excessive flow.
Vaporisers with heating fluid pumped through	Heat source fails, low or no flow of thermal fluid.	Electrical power failure. Switchgear fault. Pump mechanical failure.

4.2 Consequences of low temperature

Every material that is susceptible to brittle fracture has an associated "ductile-to-brittle transition temperature" (DBTT). The DBTT temperature is that temperature below which the Charpy impact value shows a very rapid decrease and failure occurs without plastic deformation, e.g. without the occurrence of a significant amount of stretching or yielding. The relationship between ductility and temperature for typical low carbon steel is illustrated in Figure 1. Low carbon steel shows a decrease in the fracture energy with decreasing temperature. Common structural materials such as carbon and low-alloy steels are not suitable for low temperature equipment and are susceptible to brittle fracture at these lower temperatures.

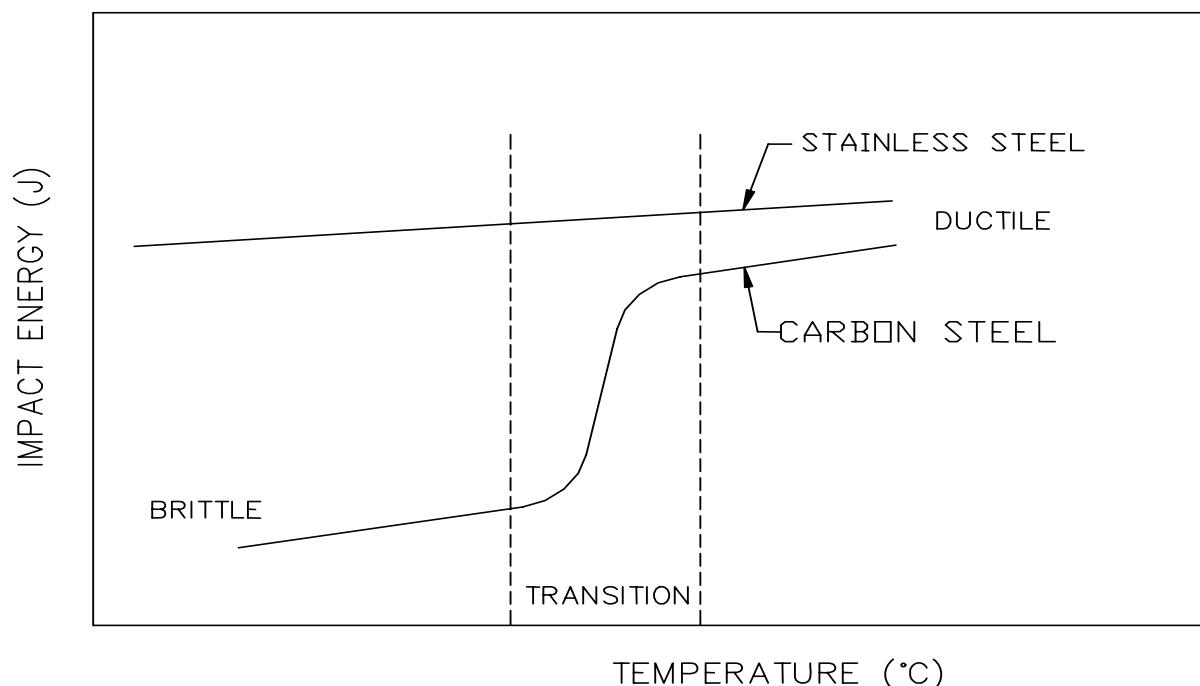


Figure 1: Relationship between impact energy and temperature for carbon and austenitic stainless steels.

Austenitic stainless steels are tough and remain ductile at low temperatures.

Materials such as stainless steels, aluminium, brass and copper do not exhibit any ductile/brittle transition and may be used down to cryogenic temperatures.

Any piece of equipment (pipe, vessels, valves etc.) that could be subjected to low temperatures shall be assessed to ensure it is suitable to withstand the temperature.

When considering the use of non metallic materials downstream of vaporisers, the low temperature properties of the material must be evaluated, before a decision to use it is made.

Brittle failure can result in the following hazardous consequences:

Pressure Volume (PV) energy release: Release of the pressure energy contained in the equipment. The pressure energy can cause damage or injury from blast wave pressure forces on structures and personnel. Buffer vessels and large diameter piping associated with vaporisers and constructed of materials that are susceptible to brittle fracture present a particular hazard to personnel because of the increased PV energy available on failure and the consequent increased area in which injury or fatality could occur.

Fragmentation of equipment: Propelling of fragments and whole pieces of the failed equipment at high velocity away from its point of origin is capable of causing injury to personnel or further damage to equipment adjacent to the fragmented equipment.

Loss of containment: The uncontrolled release of the contained process fluid has potential for increasing the hazardous consequences beyond the zone affected by equipment fragmentation and overpressure. Process fluids that are released can introduce hazards to personnel and equipment, depending upon the physical and chemical properties of the fluid.

Cryogenic liquids escaping from the equipment can result in a large liquid spill and vapour cloud. Cryogenic burns, obscured vision, and collateral damage to adjacent equipment are all possible.

Toxic fluids will cause adverse health effects in personnel or possible death if sufficient exposure occurs to a toxic concentration of process fluid. No toxic cryogenic liquids are covered by this document, but the result of the brittle fracture in, for example, a nitrogen cryogenic vaporisation system used for purging in a chemical plant may be a release of toxic material from the user's process.

Flammable fluids such as hydrogen, ethylene and methane will form a combustible vapour cloud or jet. Ignition of the cloud will cause an overpressure that will add to the effects of the release of pressure energy. Jet fires, flash fires or pool fires may continue after the release of product and may result in burn injuries to personnel and/or equipment damage.

Oxygen release will cause the formation of an oxygen-enriched atmosphere that can support rapid combustion of many materials.

Asphyxiant release [e.g., nitrogen, argon] will cause the formation of an oxygen-deficient atmosphere, with risk of fatality or injury to persons within the oxygen-deficient atmosphere.

Cold burns: A secondary hazard is the risk of cold burns from skin contact with cold piping and vessels following the product release.

Availability of gas supply: Embrittlement and failure of system will also result in a failure to supply the customer, which in some cases may create an additional hazard for the customer. Activation of a low temperature shutdown system will also interrupt customer supply, but supply can be re-established much more quickly than in the case of a brittle failure.

5. Types of vaporiser

The following types of vaporiser are covered by this document:

5.1 Ambient Air Vaporisers

Ambient air vaporisers are vaporisers where convection currents in the atmospheric air close to the surface of finned tubes utilize the sensible heat of the surrounding air to provide heat for vaporisation and to raise the vaporiser outlet gas temperature to a value below that of the ambient air.

5.2 High Thermal Ballast (HTB) Vaporisers

An HTB vaporiser is one that has a significant amount of stored energy ballast remaining at a time of power outage, energy-input malfunction, or overdraw condition. On failure of utility, the time taken for the outlet temperature to fall to the embrittlement temperature will be several minutes or more. An energy-input malfunction can occur by loss of steam or burner fuel or electrical heating to a water bath vaporiser or by ice and frost build up on a forced draft or ambient air vaporiser. Examples of HTB vaporisers are:

- **Water bath vaporiser** - a water bath is maintained at a desired temperature by means of hot water circulation, steam injection or electrical heater elements or hydrocarbon fuel fired heaters. A vaporisation coil or tube bundle in the water bath uses the heat from the water to vaporise the cryogenic liquid and to provide superheating to raise the vaporiser outlet gas

temperature. The thermal mass of the water helps to reduce the variation in the process outlet temperature.

- **Electrically heated metal block vaporisers** - electrical power is used in electrical heater elements embedded in a metal block to heat the block. The vaporisation coil is also embedded in the block and hence heat is transferred from the block to the cryogenic fluid for vaporisation and superheating.
- **Forced draft, fan ambient vaporisers** – a fan is used to blow air across the surface of finned tubes, and so utilize the sensible heat of the surrounding air to provide heat for vaporisation and to raise the vaporiser outlet gas temperature to a value below that of the ambient air. The vaporiser has reduced vaporisation capacity when the fan is not operating.
- **Ambient air vaporisers with trim heaters** – electrical heaters are installed downstream of ambient air vaporisers, to provide superheating to raise the vaporiser outlet gas temperature above the minimum allowed temperature for the downstream system.
- **Ambient air vaporiser with switchover system** – two vaporisers or groups of vaporisers in parallel where the flow is switched between the vaporisers or groups to allow defrosting of one vaporiser or group.

5.3 Low Thermal Ballast (LTB) Vaporisers

An LTB vaporiser is one that has little or no stored energy ballast remaining at a time of power outage, energy input malfunction, or overdraw condition. On failure of the utility, the outlet temperature can fall to the embrittlement temperature in less than 1 minute. The vaporiser materials of construction and the retained mass of the heat transfer media (water, for example) define the thermal ballast.

Examples are:

- **Vaporisers with heating fluid pumped through**, without ballast, for example ambient temperature, warm or hot water, the sensible heat in the water being used to provide heat for vaporisation and to raise the vaporiser outlet gas temperature.
- **Direct steam jacketed vaporisers** - steam is injected into a heat exchanger at a controlled rate to condense on the product tubes and the latent heat from the steam is used to vaporise the cryogenic liquid and to provide superheating to raise the vaporiser outlet gas temperature to a value at or above that of the ambient air. There is no significant thermal mass to help to reduce the variation in the process outlet temperature, if the steam flow varies.

6. Design Philosophy

6.1 Inherent safety

For low temperature embrittlement, an inherently safe vaporisation system is one where the outlet gas temperature has no possibility of falling below the minimum temperature rating of the piping material or associated equipment. In such a situation, no special measures for low temperature protection are required, and hence this would be the preferred option for the system.

An example would be a vaporisation system with all downstream components and piping up to and including the final use points constructed from materials suitable for cryogenic temperatures (e.g., stainless steel, copper, brass).

6.2 Risk assessment

In all other situations, the entire system (including all process-measurement systems, temperature and flow rate monitoring and control systems) shall be evaluated by hazard review and be subject to a risk assessment. This evaluation may be done on a generic basis. Consequences need to be

evaluated when failure of the pressurised system is possible and these consequences should be reduced wherever possible (for example, by elimination of buffer vessels where not required).

The risk assessment should consider:

- the likelihood of the low temperature event, taking into account the type of vaporiser, and the existing or predicted usage pattern
- the consequences of low temperature, taking into account the nature of the fluid, the stored energy, the location of the equipment, and the likelihood of presence of people in the vicinity
- the presence of any layers of protection existing in such areas as general process design and the basic process control system
- the presence of alarms which can be responded to in a timely manner and an effective way
- any other mitigation measures or factors which reduce the likelihood or consequence of the event, e.g., frequency of inspection visits to monitor ice build-up, frosting of pipework, etc.,

These factors should be considered in determining the required probability of failure on demand of any required low temperature protection system.

International standard IEC 61511 [6] provides a methodology to determine the required probability of failure on demand of a low temperature protection system, in relation to a defined hazard rate target.

The hazard review and risk assessment shall ideally include the customer's system. Where this is not possible, due to lack of information about the customer system, then a clear battery limit must be defined with normal and abnormal process parameters.

The specification of the low temperature protection system may use any combination of the safeguards listed in the following paragraphs. Not all of the safeguards listed need to be provided, but the design of the system shall incorporate sufficient safeguards so that the assessment of the protection system results in an acceptably low risk.

Typically, safeguards consist of systems and components designed to accomplish the following:

- Minimize the probability for process demands or excursions that could cause entrainment or carryover of cold vapours or liquids from vaporisers into downstream systems, for example by throttling the flow to a maximum limit, or by using a fixed flow restriction device
- Monitor and detect low temperature, high flow rates of cold liquid, or loss of heat supply to exchangers.
- Shut off devices to stop the process flows
- Provide an alternative vaporiser or gas supply system

Typically, monitoring equipment, with associated alarms and shutdowns as required by the risk assessment, includes the following:

- Low-temperature detection in the process streams exiting vaporisers.
- Detection of loss of utilities to heating units on vaporisers.
- Low-temperature detection or low-pressure detection in the utility supply to a heating unit in a vaporiser system.

Safety shutoff devices can include the following:

- Interlocks to shut off flow of process gas exiting a vaporiser or heater
- Interlocks to shut off pumps
- In-line shutoff valves from any of the above listed equipment, including storage tanks

The probability of failure on demand of safeguards must be considered in the risk assessment. This data may be available from the equipment manufacturer, gas company data or from recognised published sources.

Any subsequent design or operational changes shall be subject to a revision of the hazard review and risk assessment.

6.3 Reliability of customer supply

As part of the risk assessment, the impact of the proposed safeguards on the reliability of supply to the customer shall be considered. This is particularly important for uninterruptible supply systems. Where required, increased system on-stream reliability may be enhanced, for example by component (or system) redundancy (e.g., two out of three voting on temperature sensors, twin parallel shut off valves, or twin vaporiser trains) or upgrading material selection to an inherently safe system.

7. Ranking of hazards

As part of the risk assessment process, the likelihood and consequence of low temperature events shall be considered. The relative severity of consequences and relative likelihood of initiating events can be ranked. The following sections provide guidance on the overall risk ranking.

7.1 Pressure volume (PV) energy

Release of the pressure energy contained in the equipment can cause damage or injury from localized pressure forces on structures and personnel. The propelling of fragments and whole pieces of the failed equipment at high velocity away from its point of origin is also capable of causing injury to personnel in the site or further damage to equipment adjacent to the fragmented equipment. Buffer vessels and large diameter piping associated with vaporisers and constructed of materials that are susceptible to brittle fracture present a particular hazard to personnel because of the increased pressure – volume (PV) energy available on failure and the consequent increased area where injury or fatality could occur from the blast overpressure wave. The severity of the hazard can be ranked in a decreasing scale as follows, where P is the maximum operating pressure in bar gauge and V is the volume of the vessel in litres.

Table 2 - PV Energy classification

PV Severity level	Type	Example
P3	Vaporiser where the product of maximum operating pressure (bar g) and the water capacity of the buffer vessel (litres) is greater than 180 bar. litres or the product of maximum operating pressure (bar g) and outlet pipe internal diameter (mm) is greater than 3500 bar.mm.	Buffer vessel downstream.
P2	Vaporiser where the product of maximum operating pressure (bar g) and outlet pipe internal diameter (mm) is greater than 1000 bar. mm but less than or equal to 3500 bar.mm or the product of maximum operating pressure (bar g) and water capacity of the buffer vessel (litres) is equal to or less than 180 bar. litres.	Large diameter piping downstream. Example: maximum operating pressure 17.5 bars g, pipe diameter 200mm (8 inch ND).
P1	Vaporiser where the product of maximum operating pressure (bar g) and outlet pipe internal	Small diameter piping downstream. Example: maximum operating pressure 10

	diameter (mm) is less than or equal to 1000 bar. mm	bar g, pipe diameter 100mm (4 inch ND)
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NOTE - The values noted above are based on a review of the groups and categories detailed in the Pressure Equipment Directive, PED 97/23/EC.[7]

7.2 Hazard of fluid

Cryogenic liquid escaping from the equipment can result in a large liquid spill and vapour cloud. Cryogenic burns, obscured vision, and collateral damage to adjacent equipment and injury to personnel are all possible. The severity of the hazard can be ranked in a decreasing scale as follows:

Table 3 - Fluid hazard classification

Hazard Severity level	Hazard Type related to PV Severity level	Example
H3	Toxic or Flammable All classes	Rupture of piping downstream of the vaporiser could result in a toxic gas release flowing back from the user system or rupture of downstream piping could result in flammable gas release from user system or from a liquid hydrogen or liquid methane or liquid ethylene vaporiser.
H2	Oxygen for PV classes P3 and P2	Oxygen release will cause the formation of an oxygen-enriched atmosphere that can support rapid combustion of many materials. Person in the vicinity who are smoking, driving vehicles or engaged in hot work are particularly at risk.
H1	Inerts for all PV classes and oxygen for class P1	Asphyxiant release [e.g., nitrogen, argon] will cause the formation of an oxygen-deficient atmosphere, which risk of fatality or injury to persons within the oxygen-deficient atmosphere.

7.3 Likelihood of low temperature

The likelihood of a low temperature event occurring is affected by the process design and degree of ballast of the vaporiser. The likelihood of the hazard can be ranked in a decreasing scale as follows:

Table 4 - Classification of likelihood of low temperature occurrence

Low Temperature Likelihood Level	Type
L2	High Thermal Ballast (HTB) Vaporisers such as water bath vaporiser, heated by steam, fuel fired or electric power. Fan assisted vaporiser or ambient air vaporiser with trim heater or switchover system.
L1	Ambient air vaporiser without switchover system.

NOTE - Low thermal Ballast Vaporisers are specifically excluded from table 4 and tables 6.1, 6.2, and 6.3 for the reasons noted in section 8.8.

7.4 Operating pattern

The likelihood of a low temperature event occurring is affected by the operating pattern of the vaporiser. The likelihood of the hazard can be ranked in a decreasing scale as follows:

Table 5 - Classification of service type

Operating pattern	Type
S2	Continuous supply or back up used for peak shaving.
S1	Only back up supply.

8 Safe Design Criteria

8.1 Vaporiser outlet materials

When the piping downstream of a cryogenic vaporiser, including the customer's supply piping and associated process equipment, is fabricated entirely of materials suitable for cryogenic temperature, a low-temperature shutoff system is not required.

Any vaporisation system requires a length of piping designed for cryogenic conditions at the exit of the vaporiser. The cryogenic pipe length shall be of sufficient length such that the gas temperature during upset conditions, possibly leading to a shutdown of the system, does not bring the equipment temperature below the ductile-to-brittle transition temperature at the end of this piping length, before appropriate corrective action is taken.

Any low-temperature-detection instrumentation required for this system shall be installed at the inlet of this run of cryogenic piping to allow the instrumentation adequate time to react to a change in the outlet conditions.

All piping and equipment (e.g., regulators and manual valves) installed in the cryogenic length of pipe shall be specified of material suitable for cryogenic service.

For pressure-relief devices located at the outlet of a cryogenic-liquid vaporiser, the inlet piping of the pressure-relief devices, and the outlet piping where appropriate, shall be specified in materials suitable for cryogenic service. Normally, relief devices shall be sized for warm-gas conditions that are expected to occur during normal operation, but must be capable of withstanding cryogenic conditions in the event of vaporiser overload or loss of a heat condition that might occur in a blocked-in condition during which the relief device would be called upon to function.

Adequate piping flexibility shall be maintained for the entire system downstream of the vaporiser, up to and including the customer's battery limit.

8.2 Ambient-air vaporisers

Ambient-air vaporisers are safer than designs requiring an external heat supply. The sizing of the unit takes into account the expected ambient conditions, the expected continuous service time of the vaporiser, and the declared flow rate and consumption pattern of the customer. Ambient-air vaporisers which have been correctly sized are more likely to prevent a hazardous low temperature from occurring at the expected conditions, than utility vaporisers. However there is still some risk of a hazardous low temperature condition occurring (e.g., continuous service, with considerable ice build up and no defrost).

High-reliability gas-supply systems use ambient-air vaporisers whenever possible.

8.3 Independent layers of protection

Low temperature protective systems typically comprise three components:

- Temperature detection device(s)
- Logic solver
- Shutoff device(s)

A logic solver may be a system of relays, or a programmable logic controller, or other electronic control system.

Where two or more LTPS are provided, the components in each LTPS should be independent of each other, to reduce the potential for common mode failure, i.e. the LTPS are independent layers of protection.

8.4 Shutoff devices and valves

Any of the following are acceptable means of shutoff for a shutoff device:

- Vaporiser outlet valve shutoff
- Vaporiser inlet valve shutoff
- Pump motor shutdown on pump(s) feeding liquid to the vaporiser

Where shut off valve(s) are used, they shall be preferably designed to fail closed on loss of power or instrument fluid. Fail-open valves shall not be used on vaporiser systems, unless a detailed risk assessment indicates that this is acceptable.

It may be acceptable for the emergency shut-off function to be incorporated into an existing control valve (for example by fitting a solenoid onto the air supply to a fail close control valve). Such a system must be adequately designed for the purpose and configured to allow periodic testing of the shut-off function and re-establishing flow across the temperature sensor after a shutdown has occurred.

However, as noted in table 1, failure of a basic process control loop may also be a cause of low temperature, so this must be taken into account when selecting the LTPS solution.

Liquefied gas must not be trapped between automatically or manually operated shut off valves or check valves without that part of the system having a pressure relief valve.

8.5 Throttling valves

Throttling valves and control circuits shall be designed to reduce the flow rate to the end user to correspond with reduced energy available to the vaporiser.

A temperature control function is often used to act on the pipeline control valve. This will reduce the flow of product as the temperature starts to fall thus preventing a low temperature condition, and a potential subsequent trip.

Should the throttling response fail to adequately control the vaporiser exit gas temperature, a shutdown of flow shall take place, unless a detailed risk assessment indicates that this is not acceptable or not necessary.

8.6 Temperature detection devices

Temperature sensing device(s) used in low temperature protection systems should be located in the gas stream close to the vaporiser outlet. Single sensing devices or one from two voting systems may be required depending on the required probability of failure on demand. A two from three voting system may be needed to activate a shutdown system for reliability reasons.

When selecting a device and designing the system, maintenance and testing requirements should be considered. For passive devices such as switches, proof test interval has a direct relationship to probability of failure on demand. It is a well known problem that capillary type devices that are fitted without a thermo well can only be tested during a shutdown, for example.

8.7 Pump systems

Where cryogenic pumps are used to feed liquefied gas to the vaporiser, the pump capacity determines the maximum flow available to the customer, and therefore the vaporisation system capacity must be matched to the pump capacity. A low temperature signal may be used to stop the pump motor, thus providing a low temperature shutdown device.

8.8 Low Thermal Ballast (LTB) Vaporisers

Due to the extremely rapid discharge gas temperature decay rate exhibited by shell-and-tube steam vaporisers and pumped fluid vaporisers without ballast on utility failure, their use is not recommended for new installations. Where their use is being considered because of limited space available, a detailed risk review is required to justify their use.

8.9 Buffer vessels and location

8.9.1 Location of buffer vessels made of carbon steel material

Buffer vessels installed downstream of vaporiser systems should be used only where essential because they present a particular hazard to personnel due to the increased pressure – volume (PV) energy available on low temperature failure and the consequent increased area where injury or fatality could occur from the blast overpressure wave.

Where used, the location of buffer vessels shall minimize the risk of having cold fluid being introduced into them. Depending of the installation type, different locations in the supply system are possible:

8.9.1. a Installation type 1 - continuous supply

Installations with a liquid vessel, vaporization system, and buffer vessel: When possible, the buffer should be installed not on the main line, but on a branched line.

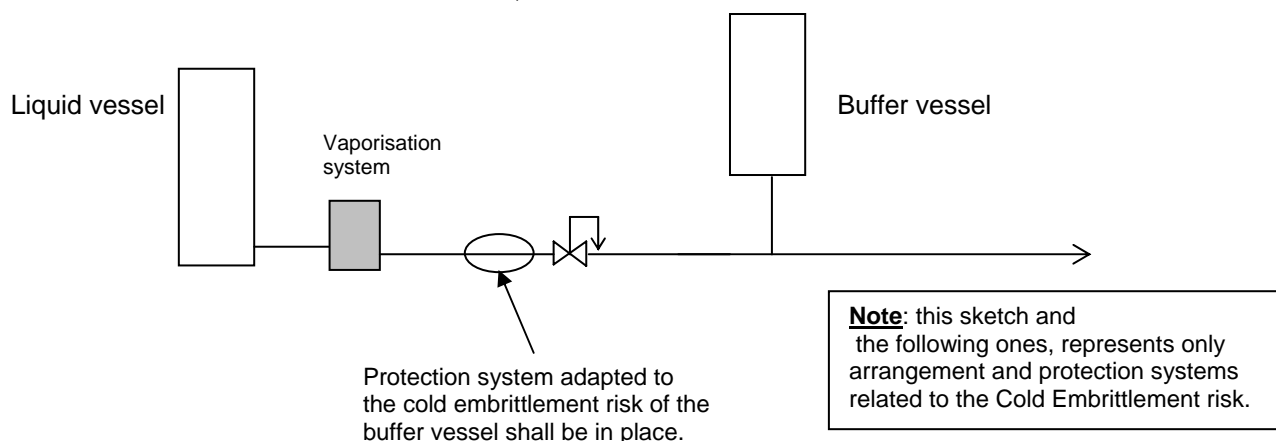


Figure 2 : Scheme 1 – Buffer installation preferred for continuous service

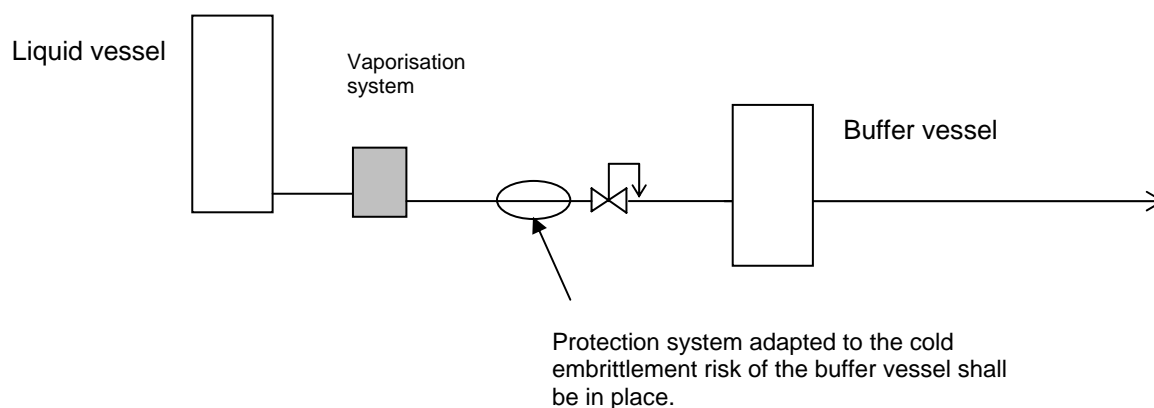


Figure 3: Scheme 2 - Other buffer installation possible for continuous service

In both cases (buffer installed on a branched line or buffer installed on the main line), a protection system adapted to the cold embrittlement risk of this buffer vessel shall be installed upstream of this buffer vessel.

8.9.1. b Installation type 2: back up supply only or back up with peak shaving

Installations with a liquid vessel, a vaporization system, an on-site gas generator, and a buffer vessel: There are two possible locations for the position of the buffer vessel:

1. Whenever possible, it should be installed on the on-site gas generator line, upstream of the vaporization system tie-in, in the product line or in a branched line, protected by a non-return valve. See scheme 3 below. In this configuration, with the buffer vessel placed on the on-site unit outlet line, the buffer does not need to be considered when deciding whether to install a protection system downstream of the vaporization system and when designing it. The buffer vessel is protected due to its position.
2. The buffer may be installed downstream of the vaporization system (in the main line or in a branched line), but in that case, a protection system adapted to the cold embrittlement risk of this buffer vessel shall be installed upstream of this buffer vessel. See Scheme 4 below.

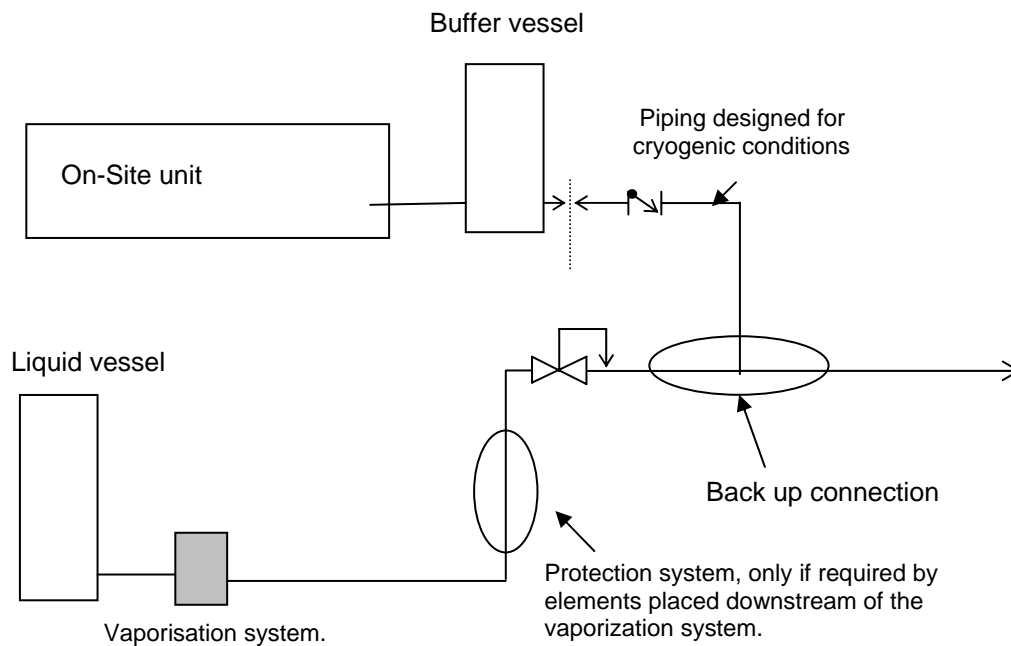


Figure 4: Scheme 3 – Buffer installation preferred for back up service

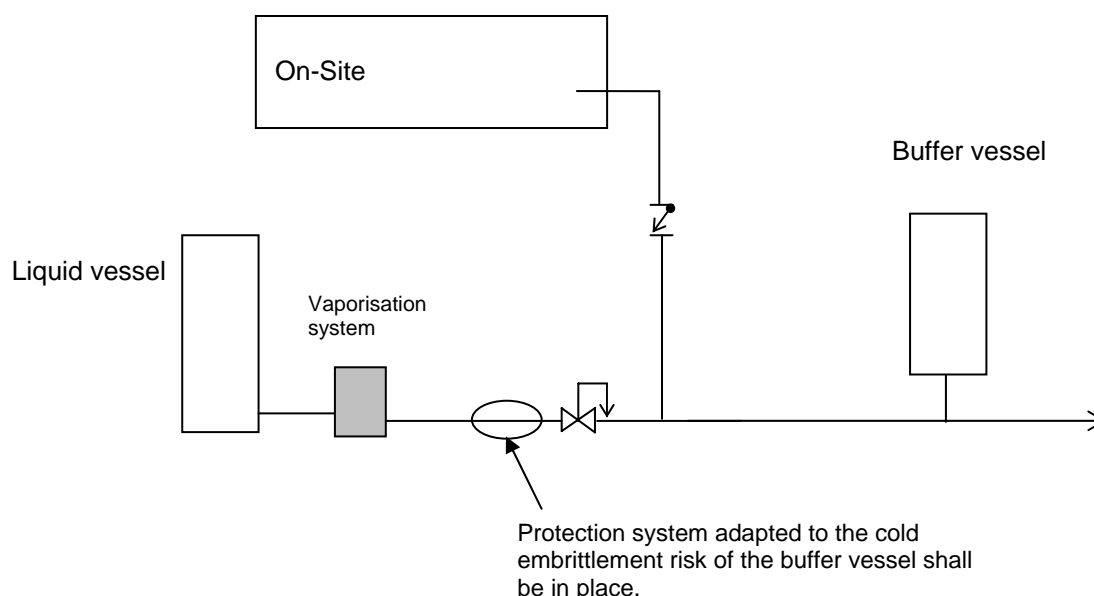


Figure 5 : Scheme 4 - Other buffer installation possible for back up service

8.10 Different vaporisers in parallel

Different vaporisers connected in parallel (e.g, ambient air vaporiser(s) as back-up to a steam heated water bath vaporiser; or the addition of a second vaporizer of a different manufacturer with a different performance, etc) may create situations leading to a hazard.

If the hydraulic and thermal parameters of the two vaporiser systems are not identical the cryogenic liquid flows preferentially into the smaller vaporizer which usually has a smaller pressure drop.

As this smaller vaporizer starts to become colder and the vaporization capacity is reduced, the pressure drop further decreases (due to more liquid being present in the vaporiser tubes).

If this continues, all the liquid will flow only into the smaller vaporizer system and the other one is completely unused.

The outlet temperature may then fall below the downstream design temperature, creating a hazard.

Therefore it is important to balance the flows between the vaporisers during commissioning by adjusting vaporiser inlet or outlet valves to avoid this potential hazard.

9 Considerations for low temperature protection

9.1 Uninterruptible supply system

This type of system is used for a customer or end-use process where:

- A shutdown that fully interrupts process flow to the customer cannot be safely tolerated
- Where limiting of flow is used, it must be accepted by the customer.

The requirement of uninterruptible flow of product to the use point can be provided for in four ways: see sections 9.1.1 to 9.1.4.

Due to the importance of continuity of supply, installation of a high flow and/or low temperature alarm may increase the supply reliability in certain situations. Section 10.2 describes requirements for response to alarms.

9.1.1 Materials

Use of cryogenically compatible components (i.e., stainless steel, high nickel alloys, copper, suitable gaskets, etc.) throughout the system, up to the customer's battery limit. The customer shall be duly advised that the system, up to and including the end use point, shall also be cryogenically suitable. Inherent in this approach is the need to provide adequate pipeline flexibility for the full temperature range.

9.1.2 Redundant system

Use of a redundant, independent supply system providing flow to the same use points. Each independent cryogenic supply source shall be equipped with an LTPS system.

9.1.3 Restrictive orifice

A restrictive orifice can be used in the supply system. The orifice is sized to limit the flow of the fluid for a defined maximum period of time such that the vaporiser is never overdrawn, but this requires careful calculation. This solution is applicable only for ambient air vaporisers as defined in section 5.1, and it is recommended that it be restricted to installations with a PV severity level P1 or P2 (table 2) and an hazard severity level H1(table 3) only. For this solution, a LTPS does not need to be installed.

9.1.4 Throttling valve

A throttling valve, as described in paragraph 8.5, may be used to limit the flow of the fluid so as to never overdraw the capacity of the vaporisers, but must be designed so that the valve cannot go to the fully closed position (e.g., by use of a mechanical stop device). This minimum remaining flow shall be small enough such that the vaporiser outlet temperature does not fall below the minimal allowable temperature for a defined maximum period of time. This solution is applicable only for ambient air vaporisers as defined in section 5.1, and it is recommended that it be restricted to installations with a PV severity level P1 or P2 (table 2) and an hazard severity level H1(table 3) only . For this solution, a LTPS does not need to be installed.

9.2 Interruptible supply requirements

Any of the above low temperature protection methods listed under "Uninterruptible Flow" may be used in situations where flow can be interrupted.

9.2.1 Instrumented shut down systems

For interruptible supply requirements, two response modes are typically encountered:

- Immediate shutdown (i.e., no flow reduction prior to shutdown).
- Throttling, followed by shutdown.

The specific low-temperature shutdown trip-point chosen is a function of the pipeline material used and the applied design requirements as described below.

9.2.2. Temperature set points

9.2.2. a. Trip set point

Carbon steel or other materials not rated for cryogenic or cold fluid temperatures shall be protected from cryogenic fluid contact. National pressure vessel and piping standards or codes should be referred to in establishing the suitability of materials to be used in vaporiser systems.

For example, ASME B31.3, Process Piping, [8] defines the minimum service temperatures of certain grades of carbon steel to be -29°C, when used at the full stress values of the ASME code, without performing a Charpy Impact test. It also allows other grades to be used at lower temperatures if more stringent criteria are met.

Impact testing of carbon steels, (specifically those impact tested carbon steels that only meet the minimum requirements of ASTM, ASME or API), does not guarantee resistance to brittle fracture, but the fine grain size of these 'low temperature' steels does provide some resistance to brittle fracture initiation.

The material selection and therefore the temperature setting at which the low temperature device operates should be determined by the ambient conditions and any tolerances or lags in the sensing system, to ensure that the minimum permissible temperature is not exceeded. This criterion shall, as a minimum, be used for piping up to and including the customer's battery limit. The customer shall be duly advised of his responsibility in maintaining design adequacy on his side of the battery limit.

Where other codes are applicable, LTPS trip set points should follow similar practice.

It is not acceptable to set the trip temperature lower than the downstream design temperature. The trip temperature will normally be set at a higher temperature.

Where necessary, an 'anti-tamper' device should be installed to ensure that the set trip temperature cannot be manually adjusted between periodic tests.

9.2.2. b. Throttling Set point

Flow throttling (when used) is initiated at a defined temperature that is higher than the chosen LTPS trip set point. The throttle set point temperature used is influenced by:

- Span limitations of the temperature measuring instrumentation system.
- Ambient temperature influences.
- Rate at which temperature varies as a function of flow rate.

9.2.3 LTPS for High Thermal Ballast Vaporisers (HTB)

"Slow" responding LTPS controls, appropriately matched to the vaporiser's discharge temperature decay characteristics, considering all foreseeable malfunctions, are acceptable for such applications. The distance between the LTPS sensor and the shut-off device shall be defined using the response time of the LTPS instrumentation, and fluid velocity.

9.3 IEC 61511

The IEC 61511 standard for Functional safety – Safety instrumented systems for the process industry sector, was published in the year 2003 as the process sector implementation of the generic standard IEC 61508, which addresses safety instrumented systems based on the use of electrical/electronic/programmable electronic technology. The standard promotes the concept that the safety instrumented functions are specified, designed, integrated and validated based on risk assessment. One part of the specification is to establish the needed Safety Integrity Level (SIL) of each function.

The solutions presented in section 10 are based on a qualitative risk ranking approach, using good industrial design practice and many years of experience in the gas industry, rather than the approach described in IEC 61511. However the IEC 61511 standard can be used as a method of supporting the risk assessment and system design process described in this document.

10. Solutions

Low temperature protection requirements for vaporisers are given in Tables 6.1, 6.2 and 6.3.

10.1 General considerations for LTPS

Previous risk assessments have indicated that low temperature protection systems must be provided where a low temperature embrittlement hazard exists. The probability of failure on demand of the LTPS should be of an appropriate level relative to the likelihood of the low temperature event occurring, the consequences of the embrittlement and the presence of any other safeguards. As a general rule the system shall be protected by preventing downstream piping and equipment from becoming too cold by detecting cold temperature exiting the vaporiser and either:

- automatically shutting down the vaporiser system, using one or more shut off devices and one or more temperature detection devices,
- or as described in the tables, providing a low temperature alarm as protection in certain situations, subject to the response requirements noted in paragraph 10.2.

One or more sensors on utility supply (for example, low water flow switch, low steam pressure switch, etc.) may also be used to activate an alarm, subject to the response requirements noted in paragraph 10.2.

10.2 Response to alarms

Where Table 6.1, 6.2 or 6.3 indicates that LTPS can be provided by alarms, it is essential that the location can be reached by a plant operator, maintenance technician or trained customer representative in sufficient time to be able to respond to a low-temperature-alarm condition. The alarm signal must be transmitted to a location which is staffed 24 hours / day. A contingency plan and administrative procedures must be in place for when this alarm is activated, to prevent brittle fracture. This may include switching between parallel banks of ambient vaporisers, limiting the customer flow rate, increasing utility supply, starting up a redundant vaporiser system, etc.

Where the location cannot be reached in sufficient time or adequate response cannot be provided on site, low temperature shut off is required.

10.3 Recommended solutions for specific situations

Tables 6.1, 6.2 and 6.3 are qualitative rankings of low temperature protection systems relative to perceived risk of a low temperature event occurring, based on the experience of EIGA members, taking into account the secondary effects from gas release as well as blast energy and the relative likelihood of the event occurring, and also taking into account the operating pattern and type of vaporiser.

A documented risk review should be carried out in all cases. Generic risk reviews may be developed for standard designs and installation locations. The following tables list recommended minimum protection systems for defined situations.

Additional alarms may be recommended by the specific risk review, and the number and type of alarms will depend on type of vaporiser. For utility vaporisers, alarms should be considered for loss of any utility.

Periodic review, with the customer, of consumption through the vaporiser system may be necessary, and LTPS may need to be modified to reflect changes in consumption, or additional vaporisation capacity may need to be added.

Not all options for LTPS are listed in Tables 6.1, 6.2 and 6.3.

Other options are listed in section 9, such as the use of throttling valves, orifices, etc, and these options may also be considered in the risk assessment for the installation.

Table 6.1 - TABLE FOR LTPS SELECTION – PV Severity level P1

Hazard Severity level Table 3	Low Temperature Likelihood Table 4	Operating Pattern Table 5	LTPS Solution
H1	L1	S1 and S2	If the specific risk review indicates it is necessary, a low temperature alarm or low temperature sensor and shut off device shall be fitted. Where the risk is deemed to be low then an alarm and/or shut off device may not be needed.
H1	L2	S1	Back up service water bath vaporisers in this category shall be fitted with a low temperature sensor and shut off device as a minimum. Back up service ambient air vaporisers with trim heaters or switchover systems and fan assisted vaporisers in this category shall be fitted with a low temperature alarm as a minimum.
H1	L2	S2	Water bath vaporisers, fan assisted vaporisers and ambient air vaporisers with trim heaters or switchover systems in continuous or peak shaving service in this category shall be fitted with a low temperature sensor and shut off device as a minimum.
H3	L1	S1 and S2	This category of ambient air vaporisers shall be fitted with a low temperature sensor and shut off device as a minimum.
H3	L2	S1 and S2	These HTB vaporisers shall be fitted with a minimum of two low temperature sensors and two independent shut off devices.

NOTE - definitions of P1 to P3, H1 to H3, L1 and L2 and S1 and S2 are given in Tables 2, 3, 4 and 5

Table 6.2 - TABLE FOR LTPS SELECTION – PV Severity level P2

Hazard Severity level Table 3	Low Temperature Likelihood Table 4	Operating Pattern Table 5	LTPS Solution
H1	L1	S1	For ambient air vaporisers in back up service in this category, a low temperature alarm shall be installed as a minimum. If the specific risk review indicates it is necessary, a low temperature sensor and shut off device shall be added.
H1	L1	S2	For ambient air vaporisers in continuous or peak shaving service in this category a low temperature sensor and shut off device shall be fitted as a minimum. Additional low temperature alarms may be recommended by the specific risk review.
H1	L2	S1 and S2	Water bath vaporisers, fan assisted vaporisers and ambient air vaporisers with trim heaters or switchover systems in this category shall be fitted with a low temperature sensor and shut off device as a minimum. A sensor on utility supply shall alarm.
H2	L1	S1 and S2	These ambient vaporisers shall be fitted with a low temperature sensor and shut off device as a minimum.
H2	L2	S1	Back up service water bath vaporisers, back up service fan assisted vaporisers and back up service ambient air vaporisers with trim heaters or switchover systems in this category, shall be fitted with a low temperature sensor and shut off device as a minimum. A sensor on utility supply shall alarm.
H2	L2	S2	Continuous service or peak shaving water bath vaporisers, fan assisted vaporisers and ambient air vaporisers with trim heaters or switchover systems shall be fitted with 2 or more independent low temperature sensors either of which closes a single shut off device as a minimum.
H3	L1	S1 and S2	This category of ambient air vaporisers shall be fitted with at least two temperature sensors either of which will close a single shut off device.
H3	L2	S1 and S2	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close two independent shut off valves.

NOTE - definitions of P1 to P3, H1 to H3, L1 and L2 and S1 and S2 are given in Tables 2, 3, 4 and 5

Table 6.3 - TABLE FOR LTPS SELECTION – PV Severity level P3

Hazard Severity level Table 3	Low Temperature Likelihood Table 4	Operating Pattern Table 5	LTPS Solution
H1	L1	S1 and S2	These ambient air vaporisers in this category shall be fitted with a low temperature sensor and shut off device as a minimum. The sensor shall provide an alarm on low temperature.
H1	L2	S1	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close a shut off device.
H1	L2	S2	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close a shut off device A sensor on utility supply shall alarm
H2	L1	S1 and S2	These ambient air vaporisers shall be fitted with a low temperature sensor and shut off device as a minimum. The sensor shall provide an alarm on low temperature.
H2	L2	S1	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close a single shut off device. A sensor on utility supply shall alarm.
H2	L2	S2	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close two independent shut off devices.
H3	L1	S1 and S2	This category of ambient air vaporisers shall be fitted with at least two temperature sensors either of which will close two independent shut off devices
H3	L2	S1 and S2	These HTB vaporisers shall be fitted with at least two temperature sensors either of which will close two independent shut off devices. A sensor on utility supply (e.g., flow or pressure sensor) shall alarm

NOTE - definitions of P1 to P3, H1 to H3, L1 and L2 and S1 and S2 are given in Tables 2, 3, 4 and 5

11. Operation

11.1 Consumption monitoring

Consumption monitoring can contribute significantly to the safe operation of a vaporisation system. From an original contractual agreement and system design, customer demands will often increase as their business grows.

There are two variables that should be monitored:

- Firstly the flow-rate, which is one of the key design parameters when sizing vaporiser systems; any increase in customer usage may overload the vaporiser, which could result in a hazardous condition.
- Secondly is the use pattern, which also has a significant impact on the capability of a vaporiser, and this should be taken into account at the design stage but also monitored to ensure that any change in use pattern is observed and investigated where necessary.

The effect of increases in consumption on vaporisation systems can often be masked, particularly on ambient systems where favourable ambient conditions will compensate for increased demands and a problem may only become evident during colder ambient conditions.

Consumption monitoring can be achieved in a number of different ways including local flow metering and flow totalisation or by monitoring the liquid usage rate.

Flow metering will allow for more detailed analysis of liquid consumption. Flow metering can provide instantaneous or time-averaged high flow rate alarms, or provide an input to a flow limiting control function.

The monitoring of liquid usage is commonly carried out as a method of scheduling deliveries of liquid to the customer's storage tank. The remote monitoring of storage can be achieved by telemetry systems that log liquid level and can calculate the rate of change of liquid level. Monitoring can also be achieved by manual logging of liquid level in a storage tank or by the checking the frequency of liquid deliveries. Automatic alarms created by monitoring software, or periodic review of liquid usage can be undertaken, to ensure that the customer demand is not exceeding the design parameters of the system.

When monitoring consumption the following parameters should be considered:

- capabilities of the vaporisation system
- appropriate alarm levels for high consumption rate alarms
- the time period over which high consumption rate alarms should be set (instantaneous, hourly, daily, weekly etc.) which will be dependent on the customer application and use pattern
- action to be undertaken if high usage is detected, whether this is to trigger a design review or more urgent action if the increase is significantly above the design values

Where safe operation of a vaporizer system is dependent only on operating within the design limitations of a vaporizer system (such as ambient air vaporizer systems where there is no low temperature shut-off system or no low temperature alarm installed and where there is no flow-limiting device fitted), then a method of consumption monitoring should be in place.

11.2 Periodical Inspection

Visual inspection of the vaporiser system should be carried out at a defined frequency. The inspection should include:

- Excessive ice build up

- Frosting of pipework
- Physical damage
- Leakage of process fluid or utilities
- Change in environment around the vaporiser, such as walls or buildings installed around ambient vaporisers
- Change in degree of personnel exposure, enclosure of the system or other risk assessment factors
- Addition of a buffer vessel or other additional equipment by the customer

The frequency of inspection should be influenced by the following factors:

- Type of vaporiser
- Flow rates and usage patterns
- Frequency of low temperature alarm or shutdown operation seen in service
- Installations with no low temperature alarms or shutoff systems are higher priority for inspection

12 Periodic Testing

Periodic testing of protection systems is important for maintaining the reliability of the low temperature protective function. Appropriate test intervals and test procedures shall be developed for each system and will be dependent on the design of system, the type of equipment and the availability of the system for testing.

Where the planned installation shutdown frequency is less than the required LTPS proof test interval, the system should be designed to allow testing of the low temperature protection system without interrupting the customer's supply.

The testing procedure should take into consideration measures to prevent unplanned disruption of the supply to the customer and to control any overrides on trip devices if the testing is carried out on-line. Test records should be documented for each installation. Records of proof testing must be maintained during the life of the vaporiser system.

13 Training for gas company personnel

The following persons should be given awareness training in the possible causes and consequences of low temperature embrittlement hazards:

- Project engineers responsible for the installation of vaporiser systems and LTPS
- Maintenance managers and technicians responsible for the maintenance of vaporiser systems and for the periodic functional testing of LTPS
- Plant operators and supervisors responsible for the operation of plants and associated back up systems
- Design engineers responsible for the development of flow-sheets and specification of vaporiser systems and LTPS shall also have this awareness training, and in addition should be knowledgeable in the relevant design standards for low temperature protection systems.

14 Customer Awareness

14.1 Customer Contract

The customer contract should include an agreement on:

- estimated flow-rates and use pattern
- the design performance of the vaporizing system and the temperature extremes that the customer system can be expected to encounter
- emergency response when an accidental sudden increase of flow occurs at the customer

- the procedure to be implemented, including pre-warning time, when the customer's need of gas is increasing
- contact person and emergency phone number of the gas company
- the responsibility for maintenance, inspection, etc. of the vaporizer installation

Furthermore, the contract should specify the low temperature protection method which is used, such as

- shut off of flow,
- reduction of flow before shut off
- reduction of flow only or
- continuously flow without any low temperature protection.

The customer must be informed of the chosen method and its consequences for the supply reliability and system design on the customer's side of the interface point. The customer should also be made aware of the requirement to periodically test any protective device that is fitted, which may necessitate the interruption of supply if required.

The gas supplier shall always notify its customer in writing when the contract for a bulk-gas supply specifies that low-temperature-protection is not included in the project scope and that a risk of downstream equipment or piping failure exists if the customer overdraws the vaporiser design capacity. The project records shall maintain copies of documentation indicating the agreed selection of low temperature protection system.

14.2 Customer Training and Information

The gas supplier shall give the customer appropriate information and information/training material including the relevant Safety Data Sheet(s). It is highly recommended that the gas supplier also train all customer personnel involved in the monitoring or maintenance of the vaporizer installation. The training should include:

- Information of the gas properties including cryogenic risks
- Risk and precautions with material being exposed to low temperature
- The consequence of accidental releases of gas or liquid
- The proper emergency routines including actions to be taken, such as evacuating the immediate area
- Any contractually defined maintenance and inspection activities

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